Available online at www.sciencedirect.com
ScienceDirect
Procedia Materials Science 5 (2014) 2363 – 2368
Procedia Materials Science
www.elsevier.com/locate/procedia

International Conference on Advances in Manufacturing and Materials Engineering, AMME 2014

Analysis of Machining Mechanism in Diamond Turning of Germanium Lenses

Prasad Pawase[a,1], P. K. Brahmankar[a,2]*, R. S. Pawade[a,3] and R. Balasubramanium[b,4]

[1]*PG Student,* [2]*Professor,* [3]*Asscoiate Professor,* [4]*Senior Scientific Officer*
[a]*Department of Mechanical Engineering, Dr. Babasaheb Ambedkar Technological University, Lonere,M.S.,India-402103,*
[b]*Bhabha Atomic Research center, Mumbai,M.S.,India-400085*

Abstract

Infrared lenses are becoming vital part in military and medical applications. Germanium materials are preferable for such applications because of its highest refractivity among other materials. Different forms of lenses helps to reduce optical aberrations. To get desired dimensional and form accuracy diamond turning is preferable. Moore tools 350 UPL diamond turning machine is used to machine germanium lens of spherical form. Negative rake diamond tools are used of radius 0.05 mm and 0.75mm. Effect of machining parameters and tool condition on the lens quality has been studied. Feed, depth of cut and tool edge condition found to be responsible for dimensional and form accuracy of lenses.

Selection and peer-review under responsibility of Organizing Committee of AMME 2014

Keywords: Single Point Diamond Turning; Germanium Lenses; Form accuracy; Refractivity

1. Introduction

Infrared radiation is emitted by all objects based on their temperatures. Humans and other living things or hot spots in mechanical and electrical systems are visible at cooler backgrounds with the help of thermal imaging systems which detects radiation in the infrared range of electromagnetic spectrum (Fisher, R. et al., 2008). There are a wide range of applications that these systems are used such as medical, predictive maintenance, security, military and other civil applications. Optics is one of the vital parts of thermal imaging systems. Producing infrared optics

* Corresponding author. Tel.: +918275591124; Fax: 912140275142.
E-mail address: pkbrahmankar@dbatu.ac.in

Selection and peer-review under responsibility of Organizing Committee of AMME 2014
doi:10.1016/j.mspro.2014.07.480

with desired dimensional tolerance and surface quality is crucial. Therefore, related studies are continuously performed to decrease the cost considering the high production rate.

Traditional machining methods for producing optical parts have been highly dependent on the use of the loose abrasive processes like lapping and polishing. Indeed these processes have proved extremely successful in the manufacture of high quality planar and spherical surfaces. However, the implementation of such machining processes for the manufacture of more complex shape objectives have been far less successful when assessed from both a quality and cost effectiveness standpoint.

Single point diamond turning (SPDT) is an established ultra- precision manufacturing method used to produce optics on a variety of classical engineering materials using a single point diamond cutting tool (Rhorer, R. et al., 2010). SPDT is preferred for its unique capability to efficiently produce three dimensional freeform structures. Moreover, the components produced through an SPDT operation have much better metallurgical structure than the one obtained through polishing and lapping processes (Saito, T. et al., 1975). This couples further with the fact that SPDT offers flexibility of generated figure, better step-definition, deterministic form accuracy and economy of fabrication time (Brinksmeier, E. et al., 2012). Therefore, SPDT of germanium is of significant technological interest and economic advantage for various industrial applications. The aim of this work is to analyze critical machining parameters and tool condition which is responsible for dimensional and form accuracy of the lenses. Typically form accuracy of an optical component is measured in optical fringes. High quality optics are required to have accuracy's in the range of 214 up to λ/50, where λ ranges from 535-633 nm depending on the lens manufacturer. The most widely used value for λ is the wave length of a Helium Neon laser which is 633 nm. Form accuracy of high quality optics is stated either in transmission or as a surface wave front error (Zygo Precision Optics Catalogue, 2010).

Blake and Scattergood (Blake, P.N. and Scattergood, R. O., 1989) studied about ductile regime machining of germanium and silicon. Lower surface roughness on germanium and higher surface roughness on silicon ware observed due to difference in tool wear rate. Jasinevicius et al. (Jasinevicius, R.G. et al., 2005) performed experiment machining of mono-crystalline silicon with (111) orientation by single point diamond turning machine. Changing the feed rate from lower to higher values changes the mode from ductile to brittle and decreases the surface finish. Yan et al. (Yan, J., Syoji, K., Tamaki, J., 2003) studied the wear of diamond tools while machining single crystal silicon by ultra-precision diamond turning. They found change of machining from ductile to brittle mode as a result of tool wear. Leung et al. (Leung, T.P, Lee W.B, Lu, X. M.,1998) diamond turning of silicon single crystal on a commercial diamond turning lathe They emphasized that the success of the turning process depends on optimizing the machining parameters such as feed rate, depth of cut, tool rake angles, the cutting lubricants and the crystallographic orientation of the crystal being cut. In the study of Shimomura et al. (Shimomura, O. et al., 1974), silicon and germanium have been studied and it was shown that amorphous silicon reversibly transforms to metallic phase with b-tin structure under high pressure. Morris et al. (Morris, J.C. et al., 1995) studied phase transformation in semiconductors and noted that the high pressure over 10 Gpa under cutting tool causes phase transformation from diamond cubic to metallic phase and the ductility of metallic phase provides the necessary plasticity to semiconductors for ductile mode machining. Chao (Chao, C. L. et al., 2002) machined silicon wafers with (111) and (100) orientations by using Rank Pnuemo ASG-2500 machine. Tool geometry has profound effects on the material removal mechanisms involved and on the tool wear rate. It is possible to reduce tool wear and improve surface finish by carefully modifying the tool shape. Shibata et al. (Shibata, T., Fujii, S., Ikeda, M., 1996) demonstrated the dependence of crystallographic directions in ductile-regime machining. Diamond turning experiments were performed along all directions on (001) and (111) planes of single crystal silicon. It was found that the crystallographic orientation affected the ductile machining for a (001) crystal significantly more than for a (111) crystal. Maximum percentage of ductile mode material removal in (001) was 60% whereas for (111) crystal this ratio almost reached 95% for a chip thickness value of 1 μm. It is thus resulted that very few authors have experimented germanium as lens machining in view of the above, this work attempts to fill the gap in the literature.

2. Experimental Work

2.1 Tooling and Workpiece

For the experiment total three type of mono crystalline diamond tools are used. Out of 0.05 mm and 0.75 mm radius tools are non-controlled waviness and 0.75 mm tool is having controlled waviness. All tools are negative rake of 25 degree and with 10 degree clearance angle. Optical grade germanium spherical lens of 35 mm diameter and 11 mm thickness is used. One surface is convex of radius of curvature 19 mm and other surface is concave of radius of curvature of 16 mm. optical grade germanium Mono crystalline nature with (111) orientation and diamond cubic crystal structure. Resistivity is 5/20 Ohm-cm. it is silvery gray, brittle and semi-metallic materials. The transmissivity of germanium is high and homogeneous within 2 to 12 μm wavelength infrared band in electromagnetic spectrum. Material obtained by using Czochralski Crystal Growth Method.

2.2 Machine setup

Machining setup include experimental arrangement, tool setup and workpiece setup.

2.2.1 Experimental Arrangement

In this experimental setup, a single point diamond turning machine, Nanotech 350 UPL of MOORE Tools is used. During machining applications, lens is mounted on aerostatic spindle which can travel in X axis. Tool holder mounted on hydrostatic guideways which can travel in Z axis. By the simultaneous control of these two axes, flat and spherical surfaces can be machined.

Before the machining, optical part is attached to the chuck using vacuum as shown in Fig. 1 and usually centred manually using a dial indicator. The position of the workpiece is also critical to manufacture precise surfaces on optical parts. After the part is placed correctly, the rotating workpiece is machined with a diamond tool.

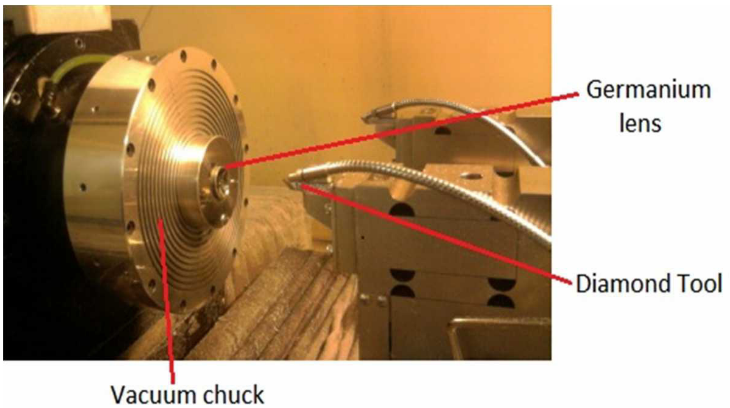

Fig. 1. Experimental setup on diamond turning machine.

2.2.2 Tool setting

Tool setting is important thing to get desired surface finish. In this experiment, tool height setting is carried out by tool height set camera which is mounted on spindle base. Clear image of cutting edges shows perfect setting of tool height. If tool is above the centre then conical peak generated and if tool is below the job centre then cylindrical peak is generated. While machining it is very important that tool must reach to the centre. Tool pass to the centre of job then it will creates ‘W’ like surface roughness pattern. If the tool do not reach to the centre then it will create ‘M’ like surface roughness pattern. By observing these values on form talysurf perfect centering is carried out.

2.2.3 Workpiece Setup

Germanium lens is placed on the aluminium fixture and both of these are further placed on the vacuum chunk. The probe of dial indicator is touched to the outer diameter of the fixture and part was rotated by 360 degree. According to positional deviation, workpiece fixture is hit slowly with a plastic stick on the highest point. Hitting procedure continues up to 1 µm concentricity difference of axes for a full turn of workpiece. After the tool and work-piece setup applications, part program is loaded and germanium workpiece is machined.

3. Results and discussion

For experiment, machining of spherical germanium lenses 0.05 mm radius tool of 25 degree negative rake angle and non-controlled waviness diamond tool is used. Machining parameters kept are 1000 rpm speed, 4mm/min feed and 10 µm depth of cut. Odorless mineral spirit and compressed air mixture mist is used for cooling purpose. Due to higher feed rate and depth of cut, the machining altered in brittle mode and micro cracks get generated at the surface. Surface is the brittle fractured surface with higher roughness value. Rainbow pattern is another defect observed on machined surface. This type of defect observed because the chips get trapped between tool and workpiece and rubbed on the workpiece surface. Ultimately it is due to cutting fluid that fails to direct chips away from cutting zone. Rainbow pattern observed due to white light is diffracted from the rough surface.

By reducing produced feed rate from 4-1 mm/min and depth of cut 10-1 µm, cutting speed 1000 rpm and using flood cooling method. Because of lower feed and depth of cut chip thickness lower than critical chip thickness, machining takes place in ductile mode. Machined clear surface with tri lobe pattern is observed. As shown in Fig. 2.

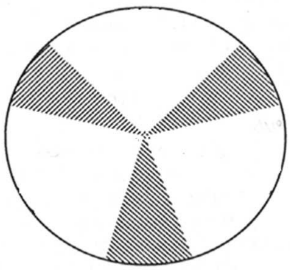

Fig. 2. Structure of tri-lobe pattern.

In the case of tri-lobe investigation under white light interferometer, it is found that tri-lobe is the effect of crystal orientation. When crystal planes meet and manifest themselves in a harder area on the surface (Shibata, T. et al., 1996). As the part rotates through one revolution, the tool will not cut as efficiently in these three zones. This will result in high spot like three spokes extending from centre.

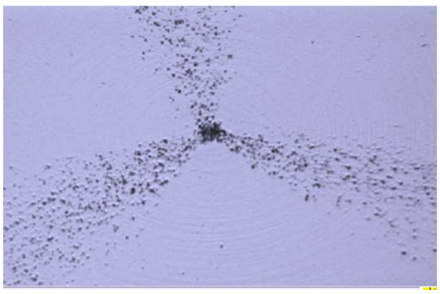

Fig. 3. White light interferometer result of Tri-lobe pattern.

Lower radius tool fails earlier and unable to create required compressive forces for machining. This type of damage was found to vary depending on the cutting direction during machining of single crystal germanium (Randall, T. et al).White light interferometer result of Tri-lobe pattern on germanium lens surface is shown in Fig. 3.

Feed rate affects the critical chip thickness which is an important parameter for ductile to brittle transition. Critical chip thickness forms at a higher depth from the surface. When feed rate increases, the pitting occurs on the machined surface and surface roughness increases. Surface roughness increases as increase in feed rate shown in Fig. 4. Optimum feed rate alters machining from brittle to ductile mode and retains good form accuracy value. Depth of cut increases and when it reaches to critical value microcracks and surface damage initiates at the region. As depth of cut increases surface roughness value increases as shown in Fig. 5.

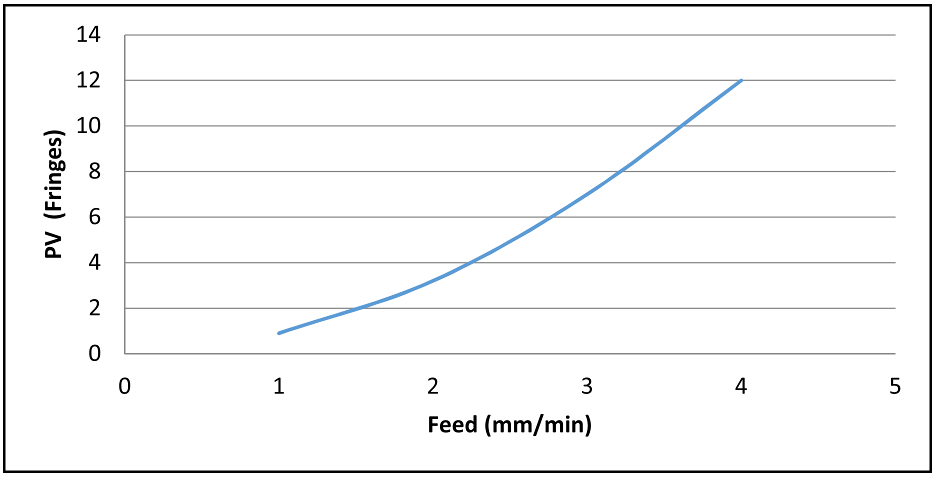

Fig. 4. PV surface roughness changes with feed.

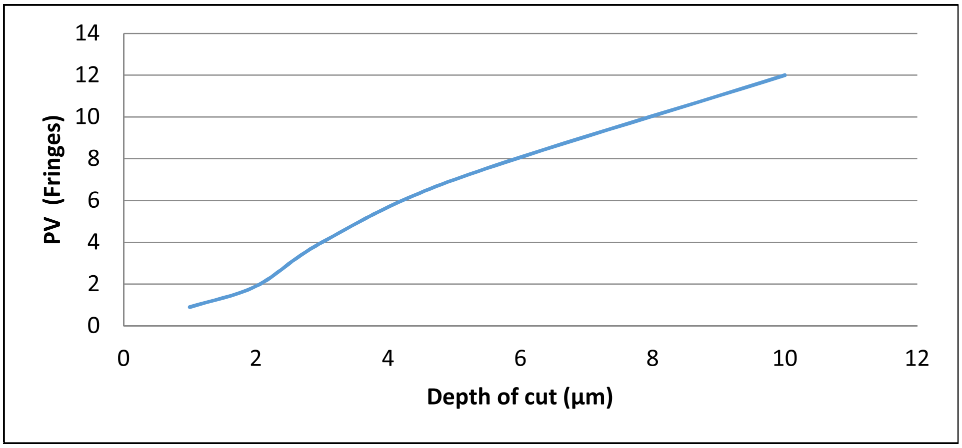

Fig. 5. PV surface roughness changes with depth of cut.

Second tool of 0.75 mm tool radius negative rake with non-controlled waviness is used for further machining. Cutting parameters are set 1000 rpm speed, 1mm/min feed and 1 µm depth of cut. Flood cooling of odorless mineral spirit is used and result of this fully finish machined surface in this case is observed without any fracture and marks. Form accuracy observed under zygo red light interferometer is 1.9 fringes.

Third type diamond tool of 0.75 mm radius negative rake with controlled waviness is used. Cutting parameters are 1000rpm speed, 1mm/min feed and 1µm depth of cut is used. Flood cooling of odorless mineral spirit is used. Form accuracy observed under zygo red light interferometer is 0.9 fringe.

4. Conclusion

Variety of machining parameters like depths of cut and feed rates along with controlled and non-controlled tools used in the diamond turning of Germanium lenses. Accurate setting of diamond tool and germanium lenses on diamond turning machine is an important step. Following are important machining and tool conditions to achieve one fringe form and dimensional accuracy.
Feed rate 1 mm/min, depth of cut 1µm and sharp edge tool allow machining in ductile mode which produce quality optical surface.
Tool condition and appropriate mist application reduces rainbow pattern.
Rake angle negative 25 degrees, controlled waviness and radius 0.75 mm single point diamond tool found capable of effective machining of germanium lenses.

Acknowledgement

The authors wish to thank Mr. Prashant Deshmukh of Mechvac Fabricators (I) PVT. LTD. Mumbai, India for providing facilities to conduct research project.

References

Blackley, W. S., Scattergood, R. O., 1991. Ductile-regime machining model for diamond turning of brittle materials. Precision engineering, pp. 95-103.

Blake, P.N. and Scattergood, R.O., 1989. Ductile Regime Machining of Germanium and Silicon, Journal of the American Ceramic Society, Vol. 73, No. 4, pp. 949-957.

Brinksmeier, E., Preuss, W., 2012. Micro-machining, Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, pp. 3973–3992.

Chao, C.L., Ma, K.J., Liu, D.S., Bai, C.Y., Shy, T.L., 2002. Ductile Behaviour of Single Point Diamond Turning of Single-crystal Silicon. Journals of Materials Processing Technology, 127, pp. 187-190.

Fischer, R., Tadic-Galeb, B., Yoder, P., 2008.Optical System Design, Second Edition, Mc graw Hill, pp.213-214.

Jasinevicius, R.G., Porto, A.J.V., Pizani, P.S., Duduch, J.G., Santos, F.J., 2005. Characterization of Structural Alteration in Diamond Turned Silicon Crystal by Means of Micro Raman Spectroscopy and Transmission Electron Microscopy, Vol. 8, No.3, pp. 261-268.

Leung, T.P, Lee W.B, Lu, X. M., 1998. Diamond turning of silicon substrates in ductile-regime. Journal of Materials Processing Technology 73, pp. 42–48.

Morris, J.C., Callahan, D.L., Kulik, J., Patten, J.N., Scattergood, R.O.,1995 Origins of the Ductile Regime in Single Point Diamond Turning of Semiconductors. Journal of the American Ceramic Society, Vol. 78, No. 8, pp. 2015-2020.

Randall, T., Walter, J., Scattergood, R., Nemanich, R., High Pressure Phase Transformation and Ductility in Diamond Turned Single Crystal Silicon, North Carolina State University Raleigh, NC 27695-7918.

Rhorer, R., Evans, C., 2010. Fabrication of optics by diamond turning, Handbook of Optics, Mc graw Hill, pp.41.3-41.4.

Saito, T., 1975. Machining of optics: An introduction, Applied Optics, pp. 1773–1776.

Shibata, T., Fujii, S., Ikeda, M., 1996. Ductile-regime Turning Mechanism of Single-Crystal Silicon, Precision Engineering, 18 (2/3), pp. 129-137.

Shimomura, O., Minomura, S., Sakai, N., Asaumi, K., Tamura, K., Fukushima, J., Endo, H., 1974. Pressure-induced Semiconductor-metal Transitions in Amorphous Silicon and Germanium. Philosophical Magazine, Vol. 29, pp. 547-588.

Yan, J., Syoji, K., Tamaki, J., 2003. Some Observations on the Wear of Diamond Tools in Ultra-precision Cutting of Single-crystal Silicon Wear,255, pp. 1380-1387.

Zygo Precision Optics Catalogue, 2010.